

Lidar Profiling of Sound Speed and Temperature in the Ocean Upper Mixed Layer

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LONG-TERM GOALS

My long term goals are the exploitation of physics for the solution of significant problems in oceanography. My interests generally lie in the direction of optics and laser interactions in the ocean.

OBJECTIVES

Our goal is the rapid and accurate measurement of upper-ocean vertical sound speed (and hence temperature) profiles in the ocean. The objective is to obtain range resolved (approx. 1 m) measurements of temperature and sound speed over a range of 100 m at an accuracy of 0.1°C and 0.2 m/s, respectively. To this end we are developing an innovative Brillouin LIDAR concept. Present results provide considerable confidence in the success of this objective.

APPROACH

When a narrow linewidth laser beam propagates through water, it undergoes Brillouin scattering which produces two frequency shifted Lorentzian lines centered symmetrically with respect to the frequency of the transmitted laser line. In pure water, the scattering spectrum consists of essentially only this doublet. However, in the presence of hydrosols, an elastically scattered central line (also called the unshifted line, or improperly the Rayleigh line) appears. The so-called Brillouin shift, that is to say the frequency shift between the central line (laser frequency) and each of the Brillouin lines, is typically 7 to 8 GHz for water. The shift is proportional to the refractive index and the sound speed in the water; hence, it also has dependence on the salinity and temperature.

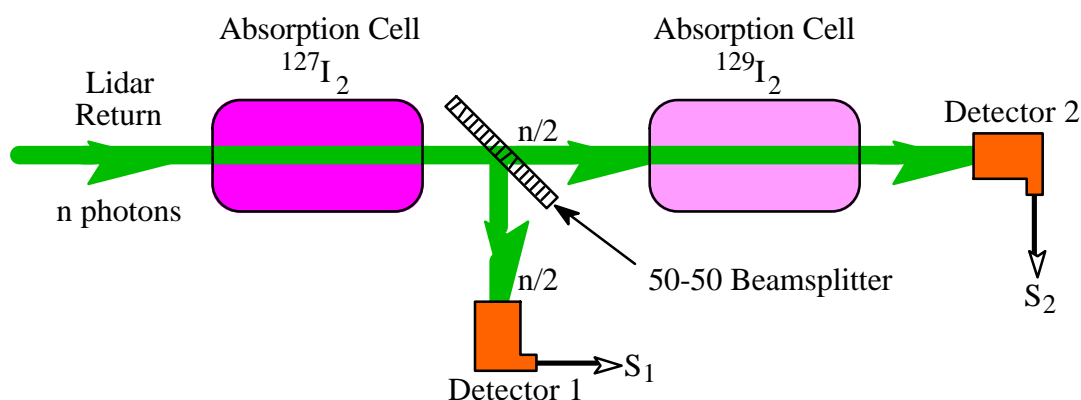


Figure 1. The lidar return first passes through a $^{127}\text{I}_2$ cell that absorbs elastically scattered light. The transmitted light is the two Brillouin shifted lines; half is detected to give signal S_1 . The other half passes through the $^{129}\text{I}_2$ cell (edge filter); the transmitted part gives signal S_2 . The ratio $S = S_2/S_1$ uniquely determines the Brillouin shift.

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Our detection apparatus to measure sound speed (temperature) using the Brillouin shift in a LIDAR return is illustrated in Figure 1. The high spectral resolution required to determine the frequency shifts is achieved using the edges of molecular absorption lines of $^{127}\text{I}_2$ and $^{129}\text{I}_2$. Simple normalization removes the dependence of the signal on variations in the amplitude of the lidar return. The concept is extraordinarily simple and robust.

Key individuals participating in the work are (1) Dr. Gangyao Xiao: He received his Ph.D. from the Shanghai Institute of Optics and Fine Mechanics. Prior to joining our group two months ago, he was an Associate Professor at the National Laboratory on High Power Lasers & Physics in China. (2) Mr. Jeffrey Katz: He is a graduate student working full time on the project; this work will form his Ph.D. dissertation. (3) Mr. Remus Nicolaescu: He is a graduate student working part time on the project; he has been a major contributor to the laser development required in the early stages of the project. (4) Mr. Andrey Matsko: He is a graduate student who has done the calculations on the new FADOF concept we are developing for the Brillouin frequency discrimination. (5) Dr. Thomas Walther: He was a post-doctoral fellow working part-time on the project, but was given a faculty appointment in September. He has provided, and will continue to provide, invaluable assistance in all aspects of the work. (4) Dr. Dahe Liu: He is a professor from Beijing University who helped in the acquisition from China of the iodine isotope ^{129}I required for the frequency analysis of the LIDAR return. He returned to China last spring.

WORK COMPLETED

(1) The $^{129}\text{I}_2$ cell was finally delivered from China this summer (15 months later than promised) and immediately tested. Although the background pressure in the cell was guaranteed to be less than 10^{-4} Torr, it was, in fact, so high that the $^{129}\text{I}_2$ lines were pressure broadened beyond recognition. We measured the FTIR absorption spectrum of the cell and found it contained large amounts of water vapor, HCl, and CO; the vapor pressure of HCl, which was the major contaminant, was in excess of 300 Torr (nearly half of atmospheric pressure).

(2) A vacuum system was constructed that met the requirements of the radiation safety people on campus and the $^{129}\text{I}_2$ cell was opened under vacuum, pumped out, and then resealed. This all worked with negligible loss of the $^{129}\text{I}_2$; we finally had a cell that gave good molecular absorption spectra.

(3) The absorption spectra of $^{127}\text{I}_2$ and $^{129}\text{I}_2$ were measured in the spectral region of the second harmonic of a Nd:YAG laser. A set of absorption lines have been found that are suitable to our concept for Brillouin frequency shift discrimination; the corresponding wavelength for the fundamental of the Nd:YAG laser is 1064.77 nm.

(4) We have made the first measurements of the Brillouin linewidth in water as a function of temperature and salinity.

(5) We have developed a fiber amplifier for amplification of narrow linewidth cw lasers to the several watt level. It was developed to amplify the cw output of a diode laser to power levels such that it could be efficiently frequency doubled for the measurement of the $^{127}\text{I}_2$ and $^{129}\text{I}_2$ spectra.

RESULTS

Technical results and their significance are discussed corresponding to each of the numbered tasks listed in the previous section, “WORK COMPLETED”.

(1) and (2) A crucial part of the concept for measuring the frequency shift in the Brillouin lidar is the absorption cell containing the molecular iodine isotope, $^{129}\text{I}_2$. Such a cell is not commercially available in the U.S. As a result of these efforts we now have a good $^{129}\text{I}_2$ cell and have thus reached this important milestone.

(3) We have simultaneously measured the absorption spectra of both $^{127}\text{I}_2$ and $^{129}\text{I}_2$ over a frequency span of several wavenumbers within the tuning range of a Nd:YAG laser. We then numerically analyzed these data to determine an optimum laser frequency for operation of the Brillouin lidar. An optimum frequency was found that corresponds to the second harmonic of 1064.77 nm. The absorption spectra over a 20 GHz spectral range centered at this frequency are shown in Fig. 2. Specifically, in the analysis we assumed a Brillouin shift, took a calculated Brillouin spectrum, multiplied it by the data of Fig. 2a, and integrated to obtain the signal S_1 (defined in Fig. 1) for that Brillouin shift. Similarly, the signal S_2 was obtained by multiplying by the transmission data of both Fig. 2a and 2b. The normalized signal $S = S_2/S_1$ was obtained by taking the ratio of these two calculated signals; it is shown in Fig. 3. The results clearly show that for this choice of laser frequency, the Brillouin shift can be accurately determined from S over the range of Brillouin shifts to be expected in the ocean.

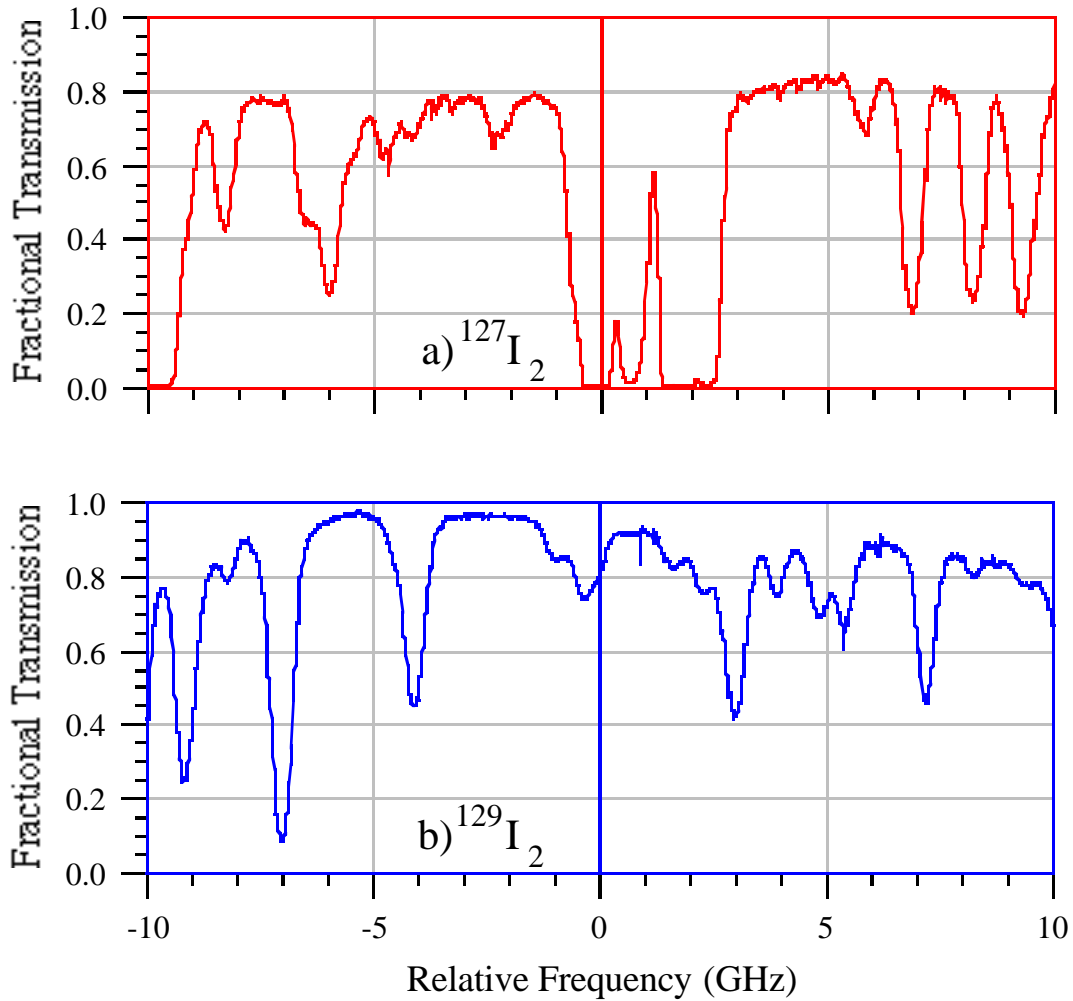


Figure 2. Transmission spectrum of the iodine cells for a 20 GHz spectral region centered at the second harmonic of 1064.77 nm: a) $^{127}\text{I}_2$ cell, b) $^{129}\text{I}_2$ cell.

(4) We have investigated the linewidth of the Brillouin peaks in laboratory experiments over a range of 1°C to 35 °C. The frequency spectrum of the back scattered laser light was analyzed using a scanning Fabry-Perot etalon. We find a surprisingly strong dependence of the linewidth of the Brillouin shifted lines on temperature. In particular, the linewidth increases (nonlinear but monotonic) from approximately 500 MHz at room temperature to 1.4 GHz at 1°C. On the other hand there appears to be little if any dependence on salinity over the range 0‰ to 70‰. This significant dependence may facilitate an independent determination of the water temperature via the linewidth and will be further investigated.

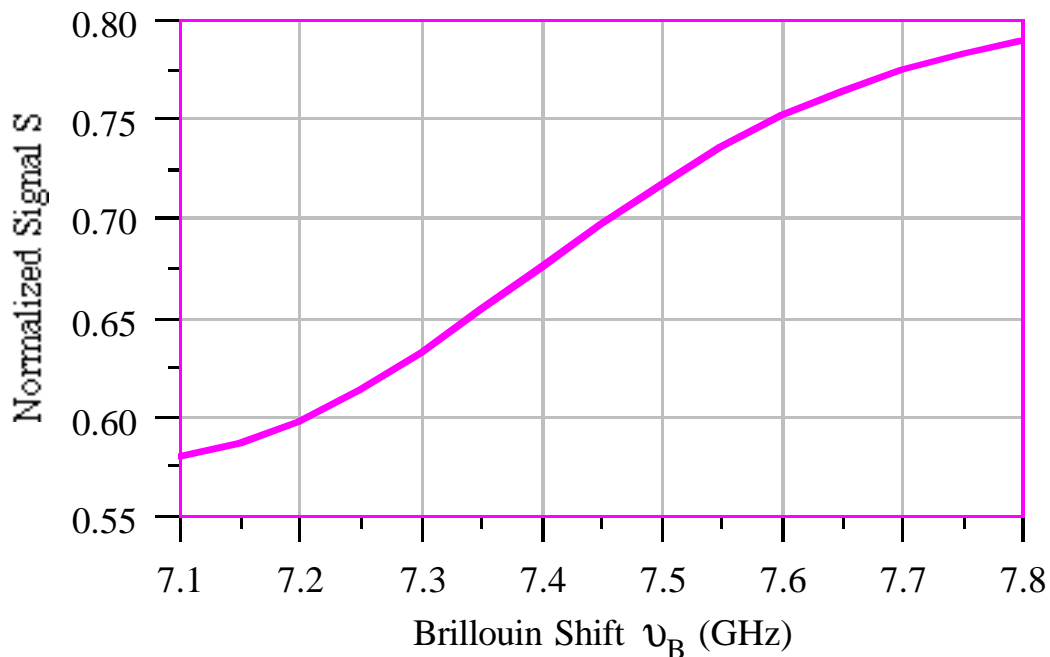


Figure 3. Normalized signal $S = S_2/S_1$ as a function of Brillouin shift using the transmission data from Fig. 2. S_2 and S_1 are defined in Fig. 1.

(5) In order to make the spectral measurements of iodine absorption and to provide a strong signal for eventually locking the pulsed Nd:YAG laser to the appropriate frequency we developed a fiber laser amplifier system. The results have been accepted for publication; #2 in the list of references.

IMPACT/APPLICATIONS

The technology we are developing to remotely sense profiles of temperature and sound velocity in the ocean will provide the capability of rapidly monitoring the upper-ocean vertical structure for much of the world's oceans and for most seasons. Such profiles will provide new perspectives on upper-ocean mixing and the oceanic internal wave field. Because of the high heat capacity and circulation in the oceans, temperature profiles are of critical importance to weather forecasting and to the understanding of ocean/atmosphere coupling and global change. Finally, sound velocity profiles are of direct strategic importance to the military mission since they provide support for both active and passive sonar functions; they would also provide an extensive new subsurface data source for operational nowcast/forecast systems.

TRANSITIONS

None at the moment.

RELATED PROJECTS

This project was co-funded with a grant from the Texas Advanced Technology Program entitled “Brillouin LIDAR for Ocean Temperature/Sound Velocity Profiling, Mine Detection, and Bathymetry”.

Specifically, in a direct spin-off from this project, we have developed a new concept for detection of submerged objects. It is a particularly significant advance in that even if an object is near or at the surface, it can still be detected with nearly 100% visibility; there are no problems with water surface reflections or bright daylight conditions.

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Publications on this grant during the last year:

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